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(54) **PHASED ARRAY DEVICE AND CALIBRATION METHOD THEREFOR**

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H03H 7/30 (2006.01)
H04L 25/03 (2006.01)
H01Q 3/26 (2006.01)

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CPC ***H04L 25/03878*** (2013.01); ***H01Q 3/267*** (2013.01)

(58) **Field of Classification Search**
USPC 375/229, 220, 222, 308, 300, 340
See application file for complete search history.

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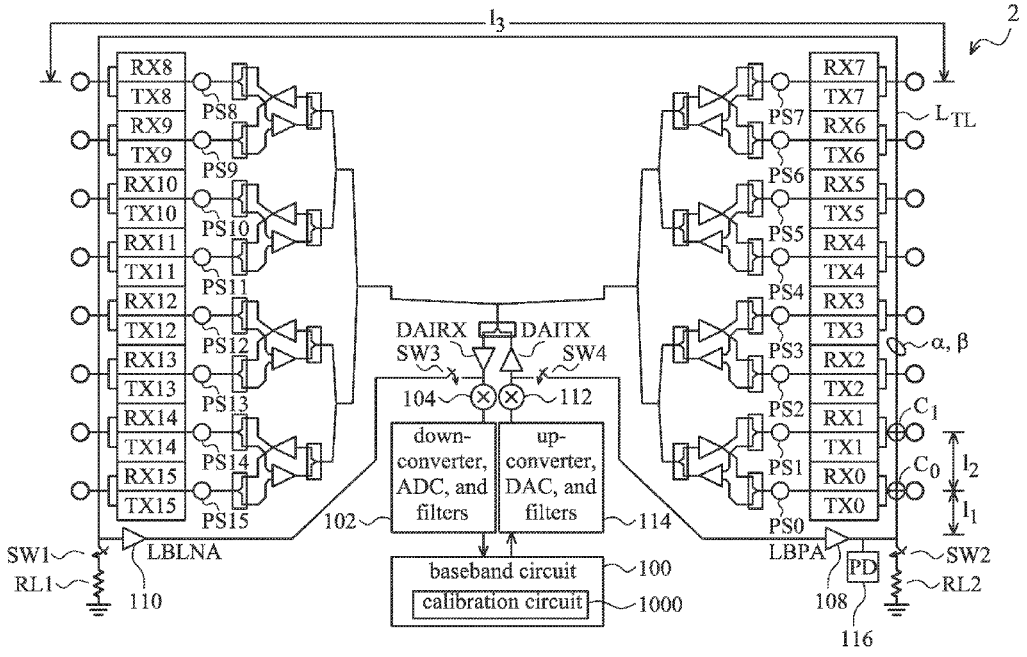
(57) **ABSTRACT**

The calibration method, performed on a phased array device including channel elements coupled in parallel by a transmission line, has the steps of: obtaining channel responses corresponding to the channel elements through the transmission line, and each of the channel responses is obtained when one of the channel elements is turned on, and the rest of the channel elements are turned off; calculating a characteristic value corresponding to the transmission line based on the obtained channel responses of the channel elements; and adjusting a channel parameter of one of the channel elements based on the characteristic value of the transmission line.

19 Claims, 6 Drawing Sheets



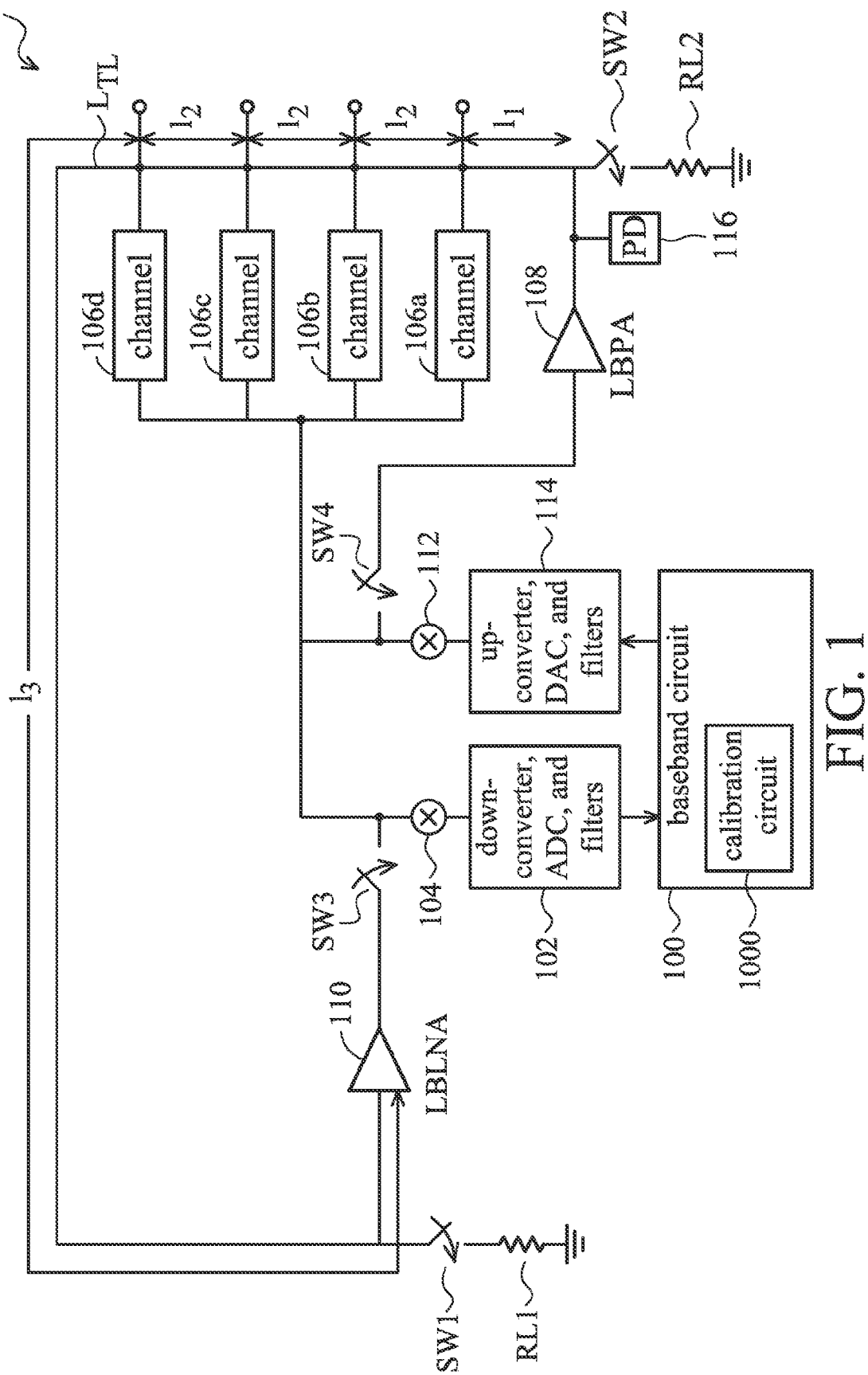

1
L_{TL}
l_2
l_2
l_2
l_1
SW2
RL2
106d channel
106c channel
106b channel
106a channel
108 LBPA
PD
116
l_3
SW4
112
114 up-converter, DAC, and filters
baseband circuit
calibration circuit
down-converter, ADC, and filters
SW3
104
102
100
1000
110 LBLNA
SW1
RL1

FIG. 1

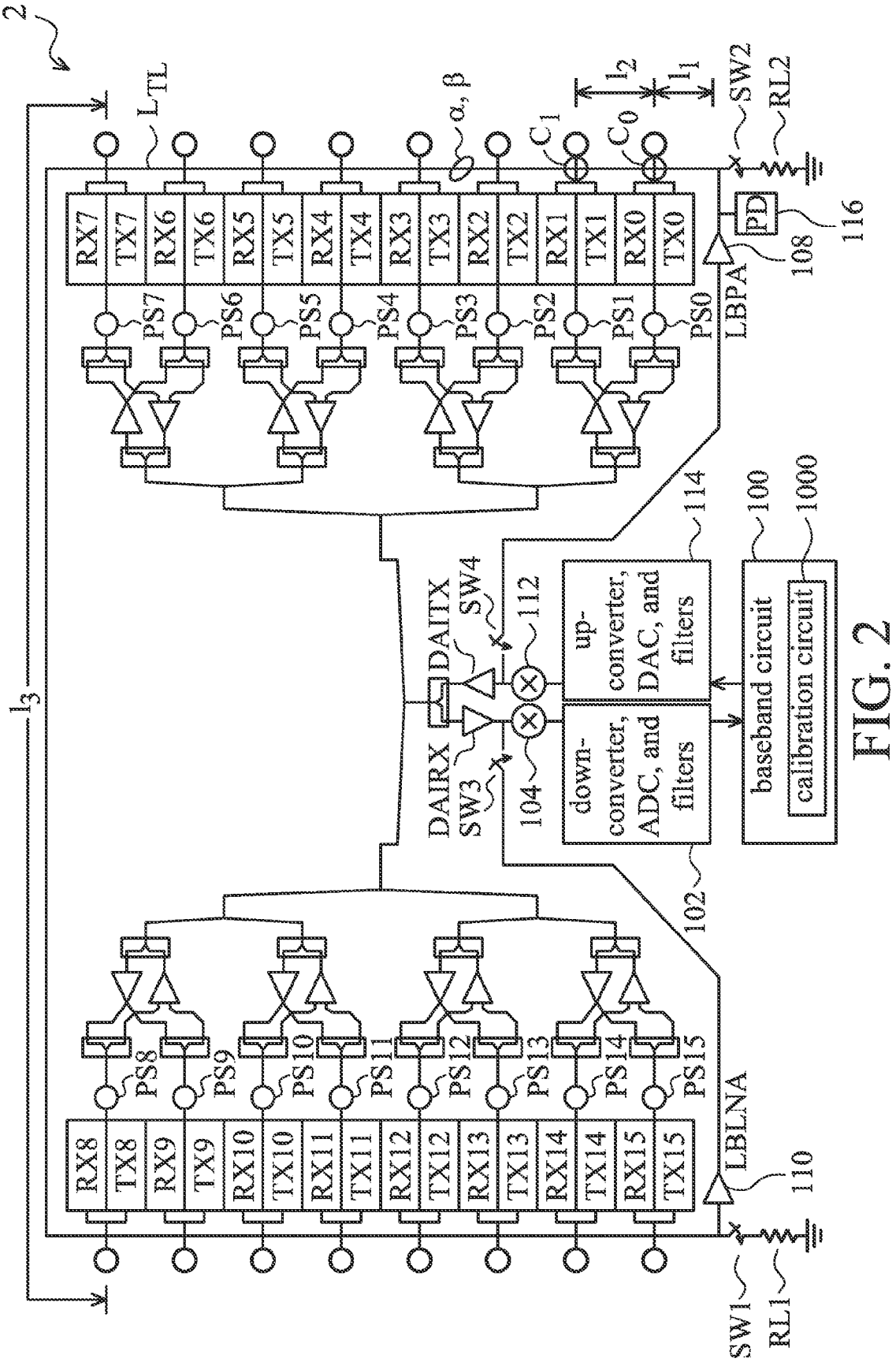

2
L_{TL}
α, β
C_1
C_0
l_2
l_1
SW2
RL2
RX7 TX7 RX6 TX6 RX5 TX5 RX4 TX4 RX3 TX3 RX2 TX2 RX1 TX1 RX0 TX0
PS7 PS6 PS5 PS4 PS3 PS2 PS1 PS0
LBPA
PD
108
116
l_3
DAITX
SW4
112
DAIRX
SW3
104
up-converter, DAC, and filters
down-converter, ADC, and filters
114
102
baseband circuit
calibration circuit
100
1000
RX8 TX8 RX9 TX9 RX10 TX10 RX11 TX11 RX12 TX12 RX13 TX13 RX14 TX14 RX15 TX15
PS8 PS9 PS10 PS11 PS12 PS13 PS14 PS15
LBLNA
110
SW1
RL1

FIG. 2

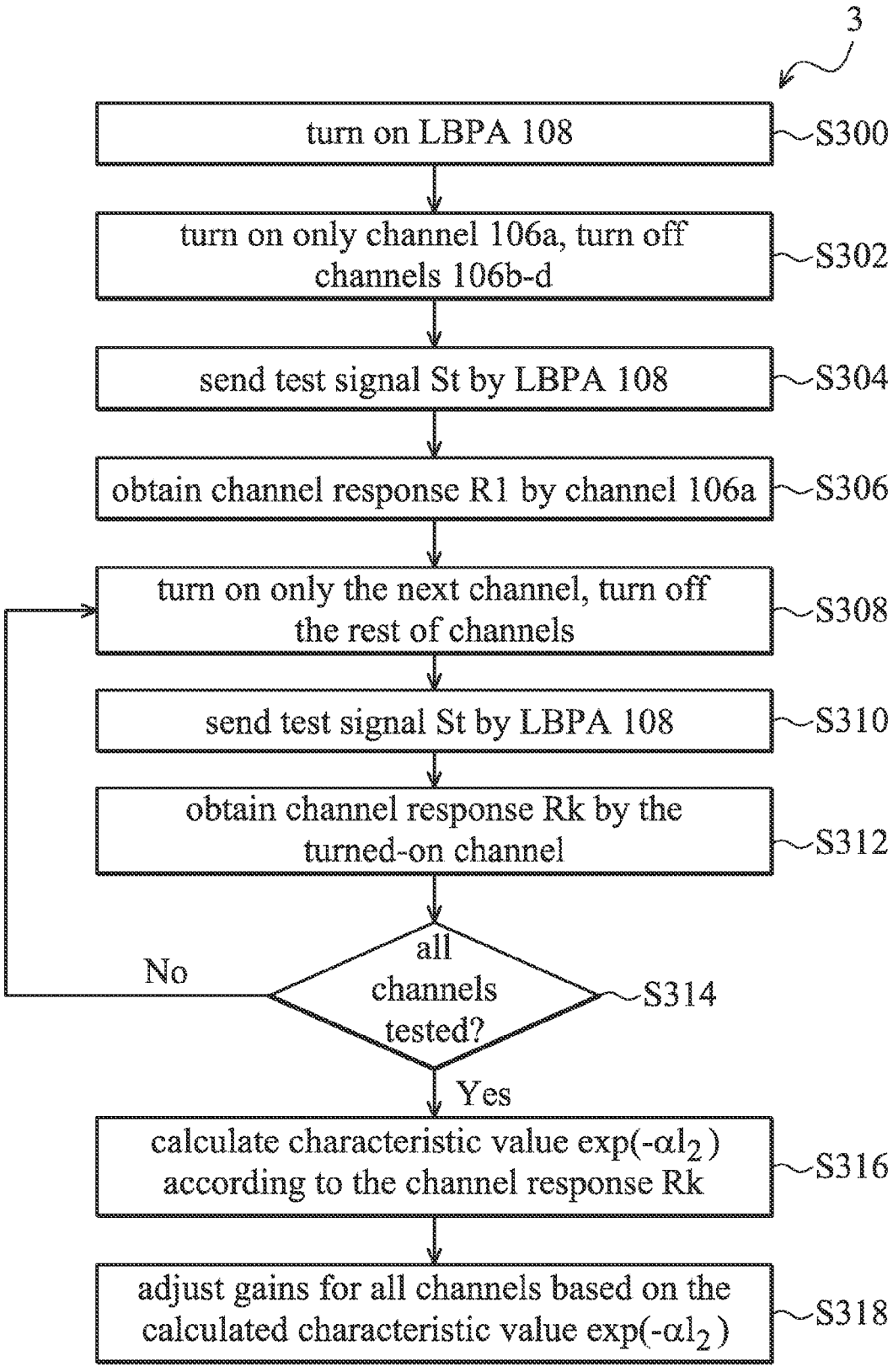

3
turn on LBPA 108
S300
turn on only channel 106a, turn off channels 106b-d
S302
send test signal St by LBPA 108
S304
obtain channel response R1 by channel 106a
S306
turn on only the next channel, turn off the rest of channels
S308
send test signal St by LBPA 108
S310
obtain channel response Rk by the turned-on channel
S312
all channels tested?
S314
No
Yes
calculate characteristic value exp(-αl2) according to the channel response Rk
S316
adjust gains for all channels based on the calculated characteristic value exp(-αl2)
S318

FIG. 3

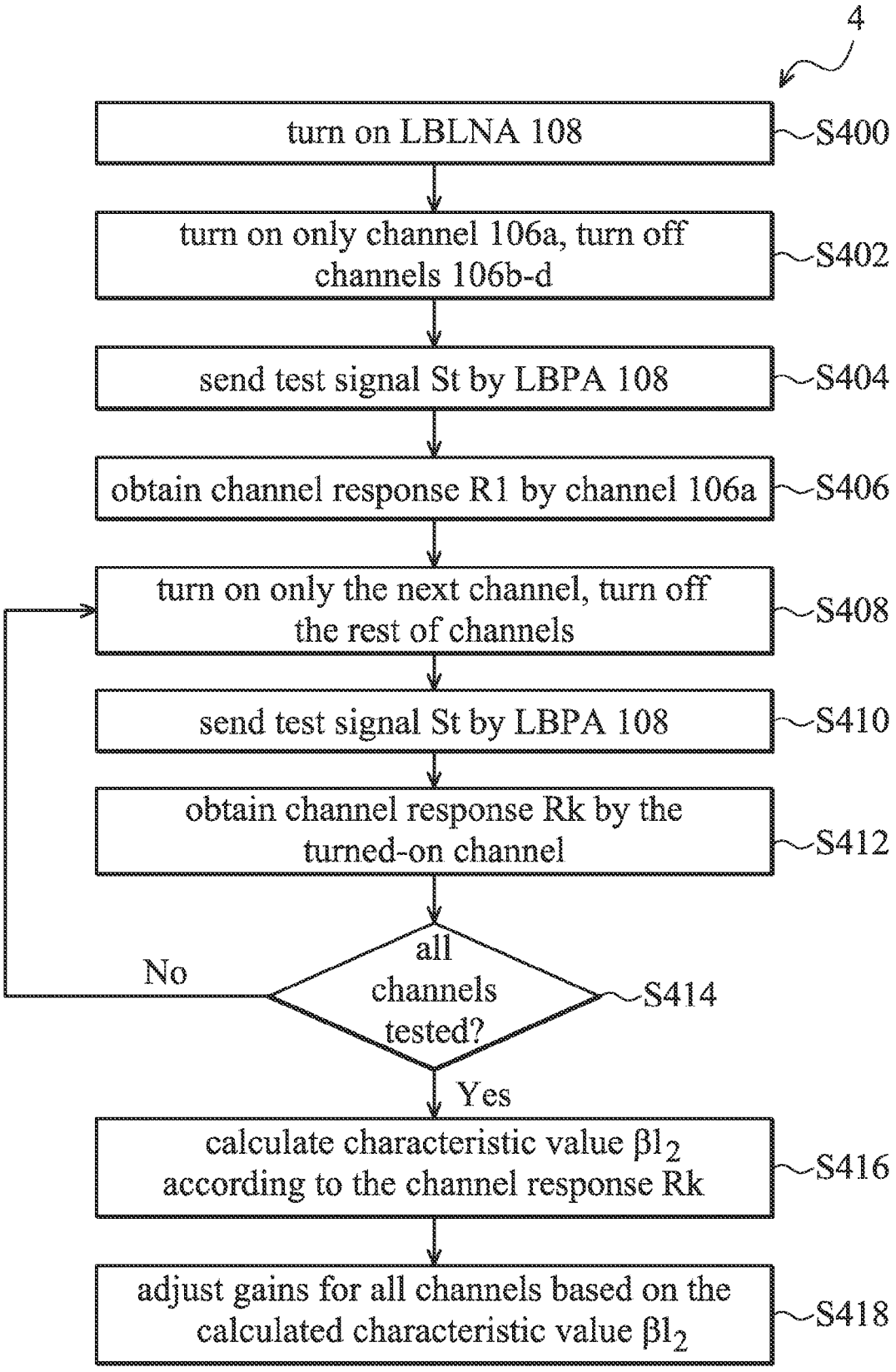

4
turn on LBLNA 108
S400
turn on only channel 106a, turn off channels 106b-d
S402
send test signal St by LBPA 108
S404
obtain channel response R1 by channel 106a
S406
turn on only the next channel, turn off the rest of channels
S408
send test signal St by LBPA 108
S410
obtain channel response Rk by the turned-on channel
S412
all channels tested?
S414
No
Yes
calculate characteristic value βl_2 according to the channel response Rk
S416
adjust gains for all channels based on the calculated characteristic value βl_2
S418

FIG. 4

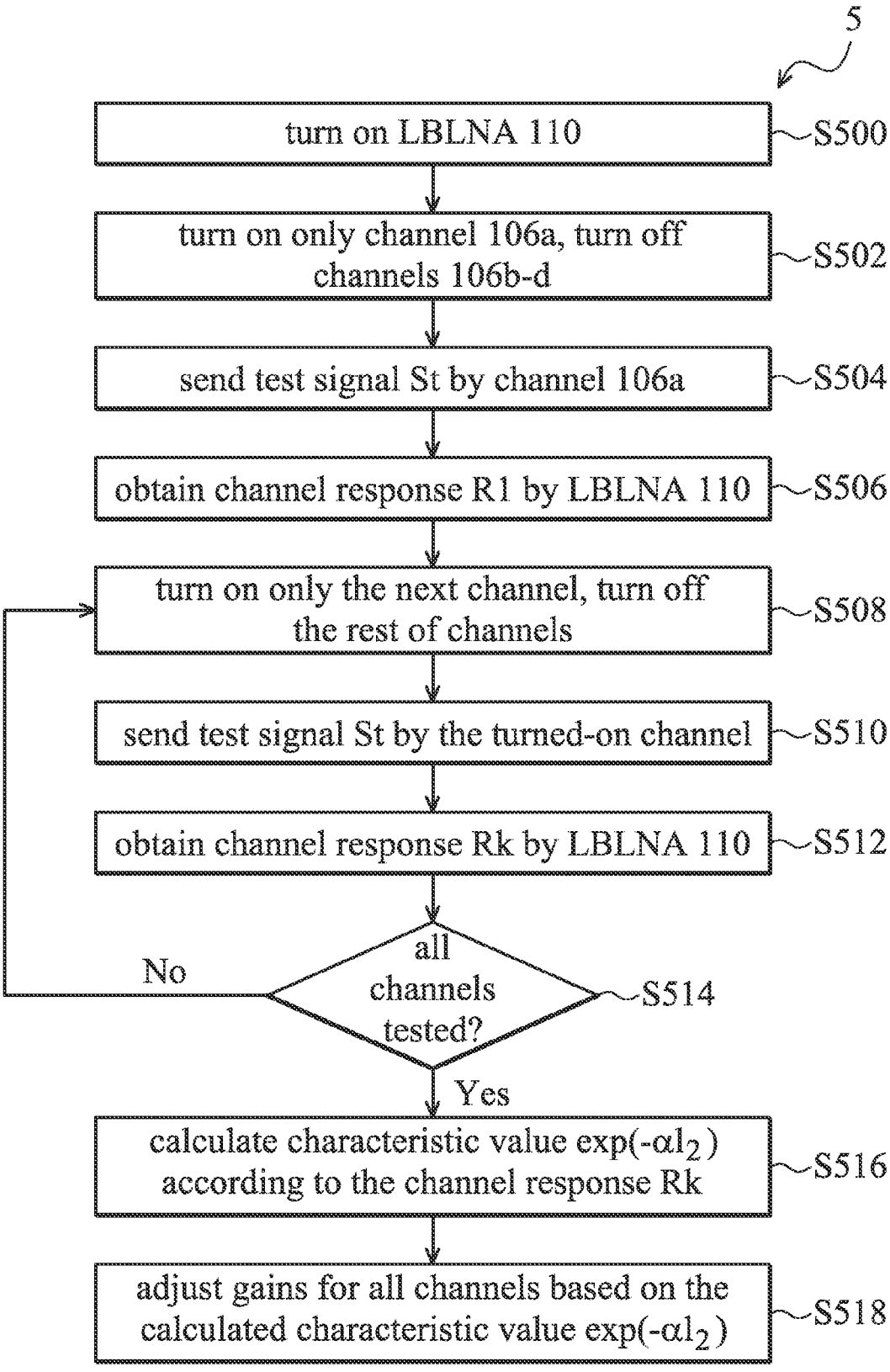

5
turn on LBLNA 110
S500
turn on only channel 106a, turn off channels 106b-d
S502
send test signal St by channel 106a
S504
obtain channel response R1 by LBLNA 110
S506
turn on only the next channel, turn off the rest of channels
S508
send test signal St by the turned-on channel
S510
obtain channel response Rk by LBLNA 110
S512
all channels tested?
S514
No
Yes
calculate characteristic value exp(-αl2) according to the channel response Rk
S516
adjust gains for all channels based on the calculated characteristic value exp(-αl2)
S518

FIG. 5

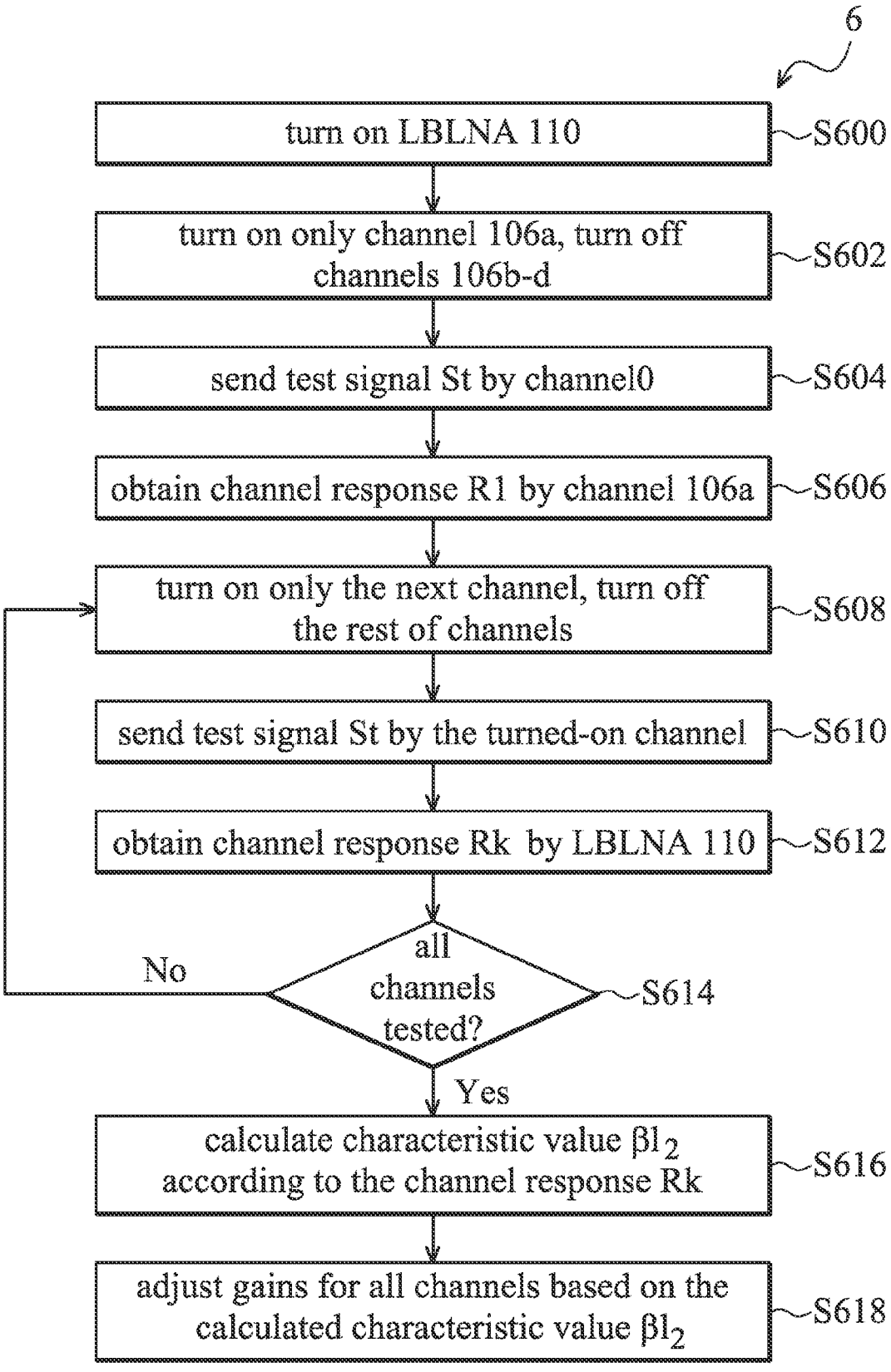

6
turn on LBLNA 110
S600
turn on only channel 106a, turn off channels 106b-d
S602
send test signal St by channel0
S604
obtain channel response R1 by channel 106a
S606
turn on only the next channel, turn off the rest of channels
S608
send test signal St by the turned-on channel
S610
obtain channel response Rk by LBLNA 110
S612
all channels tested?
S614
No
Yes
calculate characteristic value βl_2 according to the channel response Rk
S616
adjust gains for all channels based on the calculated characteristic value βl_2
S618

FIG. 6

PHASED ARRAY DEVICE AND CALIBRATION METHOD THEREFOR

CROSS REFERENCE TO RELATED APPLICATIONS

This Application claims priority of U.S. Provisional Application No. 61/558,661, filed on 11 Nov. 2011, and the entirety of which is incorporated by reference herein.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to electronic circuits, and in particular relates to a phased-array device and a calibration method therefor.

2. Description of the Related Art

A phased array is an array of antennas in which the relative phases of the respective signals feeding the antennas are varied in phases and gains relationship that the effective radiation pattern of the array is reinforced in a desired direction and suppressed in undesired directions. Corresponding to the each antenna there is a transmitter and receiver responsible for managing the phases and gains relationship of the respective signal feeding in the antenna. The phased array can utilize digital techniques for antenna beamforming, which modify phases and amplitudes of digital signals by digitally multiplying a complex weight to each antenna feed. The signals from all elements are then combined digitally in such a way that signals at particular angles experience constructive interference while others experience destructive interference, giving a number in digital form whose directional response is a function of the array geometry and the manipulated digital signals, resulting in a controllable beamforming shape. Each antenna element feeds a dedicated receiver channel element, providing amplification and selectivity. The frequency and phase responses of the receiver channel elements must track closely, over the full dynamic range of signals to be handled.

To obtain the full benefit of a digital beamforming array it is necessary to calibrate out all phase and gain mismatches of the system. The calibration routine contains injecting a test signal into each receiving channel element in turn, and measuring the amplitude and phase of the received signal. Any departures from the desired amplitude and phase can then be compensated using corrected digital weights. The performance in the presence of channel element mismatches is critical parameter of any phased array. These variations result in amplitude and phase mismatches in the radiated/received signals and hence adversely affect the beam pattern. The mismatch may arise from the intra-chip variation inherent to any process technology.

BRIEF SUMMARY OF THE INVENTION

In one aspect of the invention, a calibration method is disclosed, performed on a phased array device comprising a plurality of channel elements coupled in parallel by a transmission line, the method comprising: obtaining a plurality of channel responses corresponding to the channel elements through the transmission line, wherein each of the channel responses is obtained when one of the channel elements is turned on, and the rest of the channel elements are turned off; calculating a characteristic value corresponding to the transmission line based on the obtained channel responses of the channel elements; and adjusting a channel parameter of one of the channel elements based on the characteristic value of the transmission line.

In another aspect of the invention, a phased array device is provided, comprising a transmission line, a plurality of channel elements, and a calibration circuit. The plurality of channel elements are coupled in parallel by the transmission line. The calibration circuit is configured to obtain a plurality of channel responses corresponding to the channel elements through the transmission line, calculate a characteristic value corresponding to the transmission line based on the obtained channel responses of the channel elements, and adjust a channel parameter of one of the channel elements based on the characteristic value of the transmission line. Each of the channel responses is obtained when one of the channel elements is turned on, and the rest of the channel elements are turned off.

BRIEF DESCRIPTION OF DRAWINGS

The invention can be more fully understood by reading the subsequent detailed description and examples with references made to the accompanying drawings, wherein:

FIG. **1** is a block diagram of a phased-array device according to an embodiment of the invention;

FIG. **2** is a block diagram of a phased-array device according to another embodiment of the invention;

FIG. **3** is a flowchart of a gain calibration method for a phased-array receiver according to an embodiment of the invention;

FIG. **4** is a flowchart of a phase calibration method for a phased-array receiver according to an embodiment of the invention;

FIG. **5** is a flowchart of a gain calibration method for a phased-array transmitter according to an embodiment of the invention; and

FIG. **6** is a flowchart of a phase calibration method for a phased-array transmitter according to an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

A detailed description is given in the following embodiments with reference to the accompanying drawings.

FIG. **1** is a block diagram of a phased-array device **1** (phased array device) according to an embodiment of the invention, comprising a baseband circuit **100**, down-converter and filter **102**, modulator **104**, channel elements **106***a-d*, Loopback Power Amplifier (LBPA) **108**, Loopback Low Noise Amplifier (LBLNA) **110**, demodulator **112**, up-converter and filter **114**, power meter (PM) **116**, switches SW**1**-SW**4**, resistors RL**1** and RL**2**, and transmission line L_{TL}.

The channel elements **106***a-d* can comprise transmitter front ends and/or receiver front ends. Each channel element may suffer from a channel-to-channel mismatch due to differences in circuit elements and connection routes in the transmitter front ends and/or receiver front ends. The channel elements **106** *a-d* are connected in an equal distance $\mathbf{1}_2$ to one another by the transmission line L_{TL}. The transmission line L_{TL} connects all the channel elements **106***a-d*, the loopback PA **108** and the loopback LNA **110** in parallel, forming signal loops between the channel elements **106***a-d* and the loopback LNA **110** for detecting channel-to-channel mismatch for the transmission paths, and between the loopback PA **108** and the channel elements **106***a-d* for detecting channel-to-channel mismatch for the receive paths. Further, channel elements **106***a-d* are separated by a substantially equal distance $\mathbf{1}_2$ to one another on the transmission line L_{TL}. Only one of the channel-to-channel mismatches for the transmission paths and the receive paths may be determined at a time since the channel-to-channel mismatch detection procedures share the

same transmission line L_{TL}. Therefore, only one of the loopback LNA **110** and the loopback PA **108** is required to be activated at a time, for determining the channel-to-channel mismatch for the transmission paths or receive paths respectively.

Accordingly, when detecting the mismatches in transmission paths, the loopback LNA **110** is turned on while the loopback PA **108** remains off. The mismatch detection procedure is conducted for each of the four channel elements **106***a-d* in turn to collect a plurality of channel responses Rk corresponding to the channel elements **106***a-d* through the transmission line. For example, when taking a mismatch measurement for the transmitter front end in the channel element **106***a*, the channel element **106***a* is turned on while the channel elements **106***b-d* remain off. The baseband circuit **100** can inject a test signal St through the channel element **106***a* onto the transmission line L_{TL}, on which the loopback LNA **110** can detect the injected test signal St' to obtain a channel response R**0** for determining the channel-to-channel mismatch for the transmitter front end of the channel element **106***a*. The baseband circuit **100** can in turn send the test signal St by the remaining channel elements **106***b-d* to gather the channel responses Rk for the rest of the channel elements, with k being 1-3 corresponding to the remaining channel elements **106***b-d*. Specifically in the embodiment provided in FIG. **1**, the loopback LNA **110** can collect 4 channel responses R**0**-R**3** corresponding to the 4 phased array channel elements **106***a-d*. Based on the 4 channel responses Rk, the baseband circuit **100** can estimate a characteristic value for the transmission line L_{TL}, from which the baseband circuit **100** can further determine a mismatch parameter for adjusting a channel parameter of the channel elements **106***a-d*. The characteristic value may be associated with a transmission line attenuation constant α or a transmission line phase constant β of the transmission line L_{TL}. The mismatch parameter may be associated with a gain mismatch or a phase mismatch between the channel elements. The channel parameter is a control signal for varying amplitude or controlling a phase shift of the output signal of transmitter front end of the channel element **106**. The test signal St may be orthogonal signals at baseband.

Similarly, when testing for the mismatches in receive paths, the loopback PA **108** is turned on and the loopback LNA **110** is turned off. The mismatch detection procedure is likewise conducted for each of the four channel elements **106***a-d* in turn to collect a plurality of channel responses Rk corresponding to the channel elements **106***a-d* through the transmission line L_{TL}. For example, when taking a mismatch measurement for the receiver front end in the channel element **106***a*, the channel element **106***a* is turned on while the channel elements **106***b-d* remain off. The baseband circuit **100** can inject a test signal St through the loopback PA **108** onto the transmission line L_{TL}, on which the receiver front end in the channel element **106** can detect the injected test signal St' to obtain the channel response Rk for determining the channel-to-channel mismatch for the receiver front end of the channel element **106***a*. The baseband circuit **100** can continue sending the test signal St by loopback PA **108** to collect the channel responses Rk for all channel elements by the channel elements **106***b-d* in turn. Specifically, the channel elements **106***a-d* can detect 4 channel responses R**0**-R**3**. Based on the 4 channel responses R**0**-R**3**, the baseband circuit **100** can estimate a characteristic value for the transmission line L_{TL}, from which the baseband circuit **100** can further determine a mismatch parameter for adjusting a channel parameter of the channel elements **106***a-d*. The characteristic value may be associated with the transmission line constant α or β of the transmission line L_{TL}. The mismatch parameter may be associated with a gain mismatch or a phase mismatch between the channel elements. The channel parameter may be a control signal for varying amplitude or controlling a phase shift of the output signal of receiver front end of the channel element **106**. The channel parameters determined for the receiver front ends may not be the same as those determined for the transmitter front ends. The baseband circuit **100** may need to generate separate channel parameters or control signals for the transmitter and receiver front ends.

The baseband circuit **100** is configured to control all digital signal processing, including generating an outgoing baseband signal for the mismatch measurement or normal transmission procedure, and processing an incoming baseband signal for the mismatch measurement or normal reception procedure. The baseband circuit **100** comprises a calibration circuit **1000**, receiving the channel responses Rk from either the loopback LNA **110** or the receiver front ends of the channel elements **10***a-d*, determining the characteristic values and mismatch parameters based on the received channel responses Rk, and generating the channel parameters for adjusting the amplitude and phase of the corresponding transmitter or receiver front end so that the gain and phase mismatches between channels can be calibrated or corrected. In the gain mismatch calibration, the gains for all element channels **106***a-d* are adjusted by digital gain control signals to render substantially the same amplitudes of output signals for the element channels **106***a-d*. In the phase mismatch calibration, the phase shifts for all element channels **106***a-d* are adjusted by digital phase control signals to render substantially no phase difference among the output signals of the element channels **106***a-d*.

The determination procedure of the characteristic values, mismatch parameters and the channel parameters for channel elements **106***a-d* are detailed in gain calibration methods **3** and **5** and phase calibration methods **4** and **6**. The outgoing baseband signal can undergo a series of signal processing including digital to analog conversion, up-conversion and other filtering processes in the DAC, up-converter and filters **114** and modulation in the modulator **112** to render the loopback PA **108** or the transmitter front ends of the channel elements **106***a-d* the RF input signals. Conversely, the RF input signals coming out of the loopback LNA **110** and the receiver front ends of the channel elements **106**-*d* can go through demodulation in the demodulator **104** and filtering, down-conversion, and analog-to-digital conversion in the ADC, down-converter and filters **102** to render the channel response Rk for the calibration circuit **1000** for the mismatch detection and calibration procedure.

The loopback PA **108** and the loopback LNA **110** are identical to the circuits of the transmitter front ends and the receiver front ends respectively. The power meter **116** is attached to an output of the loopback PA **108**, at which a power level of the injected test signal St' is detected by the power meter **116**. The power level of the injected test signal St' is closely monitored so that the gain of the loopback PA **108** can be adjusted to meet a proper received power range. The switches SW**1** and SW**3** can be closed to turn on the loopback LNA **110**, and likewise, the switches SW**2** and SW**4** can be closed to turn on the loopback PA **108**. Conversely, the switches SW**1** and SW**3** can be opened to turn off the loopback LNA **110**, and the switches SW**2** and SW**4** can be opened to turn off the loopback PA **108**. The on and off states of the switches SW**1**-SW**4** can be controlled by digital control signals generated from the baseband circuit **100**. The resistor RL**1** serves to provide an input matching for the loopback LNA **110** when being connected to the loopback LNA **110** by

the switch SW1. The resistor RL2 serves to provide an output matching for the loopback PA **108** when being connected to the loopback PA **108** by the switch SW2.

The transmitter front end may contain a pre-driver, a transmitter phase shifter, a power amplifier, and switches. The transmitter phase shifter may adjust a transmitter phase of a transmitter output signal to account for a phase difference mismatch between the transmitter front ends in channel elements **106***a-d*. The transmitter phase shifter may also adjust the transmitter phase of the transmitter output signal to produce a transmitter output signal with a desired phase shift. In some embodiments, the same transmitter phase shifter is used for the phase mismatch correction and the phase shift generation. In other embodiments, separate transmitter phase shifters are used for the phase mismatch correction and the phase shift generation. The transmitter phase shifter can adjust the transmitter phase of the transmitter output signal according to a digital phase control signal (not shown). The power amplifier can increase power of the transmitter input signals with a transmitter gain, adjustable by a digital gain control signal (not shown) to produce the output signal with wanted amplitude. The receiver front end may comprise a receiver phase shifter, a low noise amplifier and switches. Similar to the transmitter phase shifter, the receiver phase shifter may adjust a phase of a receiver output signal for the receiver front end to remove or reduce a phase difference mismatch between the receiver front ends in channel elements **106***a-d*, or, may adjust the phase of the receiver output signal for the receiver front end to produce a receiver output signal with a desired phase shift. The phase mismatch correction and the phase shift generation of the receiver output signal may be implemented by a shared or separate receiver phase shifters. The receiver phase shifter can adjust the receiver phase of the receiver output signal according to a digital phase control signal (not shown). The low noise amplifier amplifies power of the receiver output signals with a receiver front end gain, adjustable by a digital gain control signal (not shown) to render wanted amplitude for the receiver output signal. In some embodiments, the transmitter phase shifter and the receiver phase shifter are implemented by a single phase shifter, shared by both the transmitter front end and receiver front end in each channel element. A pair of the transmitter and receiver front ends may share the same antenna and the same signal path to the modulator **112**/demodulator **104**, and the switch is used to select between the transmit path and the receive path.

FIG. **2** is a block diagram of a phased-array device **2** according to another embodiment of the invention. The phased-array device **2** is a 16-channel elements phased array, similar to the phased-array device **1**, except that each channel element in the phased-array device **2** comprises a transmitter front end TX and a receiver front end RX.

When the phased-array device **2** is in a factory test or being powered-on, the channel-to-channel calibration methods **3-6** can be launched to reduce or remove the gain and phase mismatches among transmitter front ends TX**0**-TX**15**, and among receiver front ends RX**0**-RX**15**. The interval between the channel-to-channel calibrations will depend on the timescale on which the channel responses may be expected to vary. The channel-to-channel calibration methods are applicable only to the channel elements spaced by the equal distance $\mathbf{1}_2$ on the transmission line L_{TL}. For example, the transmitter front ends TX**0**-TX**7** are grouped into one group, and the transmitter front ends TX**8**-TX**15** are grouped into another group for performing the channel-to-channel calibration methods **3-6**. The more elements in one group, the more accurate the gain or phase mismatch can be estimated and removed. When all transmitter front ends RX**0**-RX**15** are arranged in a loop, separated by the equal distance $\mathbf{1}_2$ to one another, there is no error in the gain or phase mismatch estimation by using the channel-to-channel calibration methods **3-6**.

FIG. **3** is a flowchart of a channel-to-channel gain calibration method **3** for the receive paths according to an embodiment of the invention, incorporating the phased array devices **1** or **2** in the invention.

Upon startup of the gain calibration method **3**, the phased-array device **1** is configured to activate the loopback PA **108**, deactivate the loopback LNA **110**, and prepare the loopback PA **108** for initiating the test signal St on the transmission line L_{TL} (S**300**). Further, the phased-array device **1** is configured to turn only on the first channel element, such as the channel **106***a*, while keeping the rest of the channel elements (channel **106***b-d*) off (S**302**), so that the channel **106***a* is the only one channel that can receive the signals from the transmission line L_{TL}. The receiver front end in the channel **106***a* is set to a default digital gain setting D_{G0} and a default digital phase setting $D_{\phi 0}$. The loopback PA **108** can place the test signal St' on the transmission line L_{TL} for the receiver front end to pick up (S**304**). In response, the first channel **106***a* can acquire the test signal St', down-convert and digitize the test signal St' to derive a first receiver channel response R**0** for the calibration circuit **1000** to determine the channel-to-channel mismatch (S**306**). The first receiver channel response R**0** can be expressed as $S_{BB0}\exp(j\theta_{BB0})$, with SBB**0** being the amplitude and θ_{BB0} being the phase shift of the channel response signal R**0** with reference to the test signal St.

The phased-array device **1** can then turn on only the second channel element **106***b* and turn off the remaining channels **106***a, c*-d (S**308**), send the test signal St' again onto the transmission line L_{TL} through the loopback PA **108** (S**310**), and obtain the test signal St' through the receiver front end of the second channel element **106***b* (S**312**). While acquiring the test signal St' from the transmission line L_{TL}, the receiver front end of the channel **106***b* is set to a default digital gain setting DG**1** and a default digital phase setting Dϕ**1**. The test signal St' undergoes every circuit element and process on the receive path via the second channel element **106***b* to be the second channel response R**1** for the calibration circuit **1000** to determine the channel-to-channel mismatch. The second receiver channel response R**1** can be expressed as $S_{BB1}\exp(j\theta_{BB1})$, with SBB**1** being the amplitude and θ_{BB1} being the phase shift of the channel response signal R**1** with reference to the test signal St. The channel-to-channel gain calibration method **3** only turn on one channel element **106** at a time, to measure the corresponding channel response specifically for the turned-on channel.

Next, the gain calibration method **3** continues to switch the active channel for taking the next channel response Rk, with k being the channel count **0-3** in the case of phased-array device **1**. The calibration circuit **1000** or a channel count circuit (not shown) can determine whether all channels in the phased-array device **1** have the channel response measurements SBBK taken for (S**314**).

When all channel responses RK are collected, the calibration circuit **1000** can now calculate characteristic value $\exp(-\alpha\mathbf{1}_2)$ for the transmission line L_{TL} according to the amplitudes S_{BBk} of the channel responses RK (S**316**). Specifically, the calibration circuit 1000 can compute a gain mismatch parameter

$\frac{S_{BBk}}{S_{BB(k+1)}}$

between any two adjacent channel elements **106**, as expressed by Eq. (1):

$$\Delta S_{BBk} = \frac{S_{BBk}}{S_{BB(k+1)}} = \exp(-\alpha l_2)\frac{G_k}{G_{k+1}} \quad \text{Eq. (1)}$$

where G_k is a current gain of a current channel element **106**;

G_{k+1} is a next gain of a next channel element **106**; and

$\exp(-\alpha \mathbf{1}_2)$ represents a transmission line gain (or attenuation) due to the transmission line length $\mathbf{1}_2$.

The channel-to-channel gain mismatch calibration is used to calibrate the channel gain G_k for all channel element **106***a-d*, so that all channel gains G_k are substantially the same to one another, or gain mismatch $G_k/G_{k+1} \approx 1$. Therefore the calibration circuit **1000** can determine the gain mismatch parameter ΔS_{BBk} for all adjacent channel elements, then determine the characteristic value $\exp(-\alpha \mathbf{1}_2)$ for the transmission line L_{TL} based on all gain mismatch parameters, as expressed by Eq. (2) and Eq. (3):

$$\Delta S_{BB1} \times \Delta S_{BB2} \ldots \times \Delta S_{BBn} = \exp(-n\alpha l_2)\frac{G_0}{G_n} \quad \text{Eq. (2)}$$

where (n+1) is a number of the channel elements **106** separated by length $\mathbf{1}_2$.

$$\Rightarrow \exp(-\alpha l_2) = \sqrt[n]{\frac{\Delta S_{BB1} \times \Delta S_{BB2} \ldots \times \Delta S_{BBn}}{\frac{G_0}{G_n}}} \quad \text{Eq. (3)}$$

Eq. (3) shows that the characteristic value $\exp(-\alpha \mathbf{1}_2)$ for the transmission line L_{TL} only depends on the gain mismatch parameters ΔS_{BBk} and (G_0/G_n). Eq. (3) also indicates that the characteristic value $\exp(-\alpha \mathbf{1}_2)$ can be determined based on a product of the gain mismatch parameters

$\frac{S_{BBk}}{S_{BB(k+1)}}$

(characteristic differences). The term (G_0/G_n) is kept within 1 dB error by circuit design or circuit configuration, therefore the gain mismatch (G_k/G_{k+1}) can be kept within 1/n dB error. The error of the determined characteristic value $\exp(-\alpha \mathbf{1}_2)$ decreases with an increase in the number n of the channel elements **106** separated by length $\mathbf{1}_2$. It follows that the accuracy of the estimated gain mismatch (G_k/G_{k+1}) increases with the number n of the channel elements **106**. It is noted that in some embodiments, all channel elements **106** are placed in a loop, each spaced by the transmission line length $\mathbf{1}_2$ to the adjacent channel element **106**, the gain G_n for the last channel element **106** can be considered as the gain G_0 for the first channel element **106**, and the term (G_0/G_n) is reduced to 1, or 0 dB error, consequently the estimated gain mismatch (G_k/G_{k+1}) can also be kept at 0 dB error.

The gain calibration method **3** can determine the gain mismatch (G_k/G_{k+1}) according to Eq. (4).

$$\Rightarrow \frac{G_k}{G_{k+1}} = \frac{\Delta S_{BBk}}{\sqrt[n]{\frac{\Delta S_{BB1} \times \Delta S_{BB2} \ldots \times \Delta S_{BBn}}{\frac{G_0}{G_n}}}} \quad \text{Eq. (4)}$$

The calibration circuit **1000** can adjust the receiver gain of the second channel element **106***b* with reference to the receiver gain of the first channel element **106***a* (S**318**), then run Steps S**308**-S**312** again for determining the channel response R**1**' of the second channel element **106***b*. Accordingly, the receiver gains of the receiver front ends can be adjusted by the digital gain control signals. Based on the new channel response R**1**', the calibration circuit **1000** can determine whether (S_{BB1}'/S_{BB0}) now approaches to the characteristic value $\exp(-\alpha \mathbf{1}_2)$ within a predetermined range set during the circuit design. The calibration circuit **1000** can adjust the receiver gain again until (S_{BB1}'/S_{BB0}) is substantially the same as the characteristic value $\exp(-\alpha \mathbf{1}_2)$.

Following by the gain adjustment for the second channel element, the calibration circuit **1000** next can adjust the receiver gain for the next channel element **106***c* with reference to the receiver gain of the previous channel element **106***b* and determine the new channel response R**2**' after the gain calibration. Based on the newly determined channel response R**2**', the calibration circuit **1000** can further determine whether the gain mismatch parameter (S_{BB2}'/S_{BB1}) is substantially the same as the characteristic value $\exp(-\alpha 1_2)$. If so, the gain calibration for the third receiver front end is then completed, and if not, the calibration circuit **1000** can continue adjusting the receiver gain of the third channel element **106***c* until the (S_{BB2}'/S_{BB1}) approaches the characteristic value $\exp(-\alpha \mathbf{1}_2)$ to the predetermined range.

The calibration circuit **1000** can perform the gain adjustment procedure for the remaining channel element **106***d*. The gain calibration method **3** is completed and exited after all receiver front ends of the channel elements **106** have been calibrated for the channel-to-channel gain mismatch.

Taking the phased-array device **2** as an example, to determine the gain mismatches for the receiver front ends RX**0**-RX**7**, the gain calibration method **3** is implemented to turn on the loopback PA **108** and turn off the loopback LNA **110** (S**300**), turn the first receiver front end RX**0** on and the remaining receiver front ends RX**1**-RX**7** off (S**302**), initiate the test signal St' on the transmission line LTL by loopback PA **108** (S**304**), obtain the first channel response R**0** by the first receiver front end RX**0** (S**306**), hence complete the round for determining the channel response R**0** for the first receiver front end RX**0**. The gain calibration method **3** then carries on to obtain the other 7 channel responses R**1**-R**7** for the remaining receiver front ends RX**1**-RX**7** based on the loop outlined in Step S**308**-S**314** until the channel responses for all receiver front ends RX**0**-RX**7** are collected. The gain calibration method **3** next is implemented to calculate the characteristic value $\exp(-\alpha \mathbf{1}_2)$ by applying the channel responses R**0**-R**7** into Eq. (1), (2), and (3) (S**316**), and adjust gain settings for the receiver front ends RX**1**-RX**7** by the digital gain control signals until all gain mismatch parameters

$$\frac{S_{BB0}}{S_{BB1}}, \frac{S_{BB1}}{S_{BB2}}, \ldots, \frac{S_{BB6}}{S_{BB7}}$$

equal to the characteristic value $\exp(-\alpha \mathbf{1}_2)$ (S**318**).

The gain calibration method **3** employs a plurality of channel responses Rk for computing the characteristic value exp $(-\alpha \mathbf{1}_2)$, thereby reducing the error in estimated characteristic value exp$(-\alpha \mathbf{1}_2)$ and increasing the accuracy for determining the channel-to-channel gain mismatch. Further, when all channel elements **106** are placed in a loop with an equal distance $\mathbf{1}_2$ to the adjacent channel elements **106**, the error for gain mismatch determination can be reduced to 0.

FIG. **4** is a flowchart of a channel-to-channel phase calibration method **4** for the receive paths according to an embodiment of the invention, incorporating the phased array devices **1** or **2** in the invention.

Steps S**400** through S**414** are identical to Steps S**300** through S**314**, reference therefor can be found in the preceding paragraph and will not be repeated here for brevity. Accordingly, the channel response R**1** for the first channel element **106***a* can be expressed by $S_{BB1}\exp(j\theta_{BB1})$, the channel response R**2** for the second channel element **106***b* can be expressed by $S_{BB2}\exp(j\theta_{BB2})$. For the channel-to-channel phase calibration, the calibration circuit **1000** reduces or removes the phase difference between channel elements, i.e., $\theta_{BBk}-\theta_{BB(k+1)}\approx 0$.

After all channel responses RK are collected, the calibration circuit **1000** can now calculate characteristic value $(\beta \mathbf{1}_2)$ for the transmission line L_{TL} according to the phase θ_{BBk} of the channel response RK (S**416**). Specifically, the calibration circuit **1000** can compute a phase mismatch parameter $\Delta\theta_{BBk}$ between any two adjacent channel elements **106**, as expressed by Eq. (5):

In step S**416**

$$\Delta\theta_{BBk}=\theta_{BBk}-\theta_{BB(k+1)}=-\beta 1_2+\theta_k-\theta_{k+1} \quad \text{Eq. (5)}$$

where θ_{BBk} is a current phase value of a current channel element **106**;

θ_{BBk+1} is a next phase value of a next channel element **106**; and

$\beta \mathbf{1}_2$ represents a phase shift due to the transmission line length $\mathbf{1}_2$.

The calibration circuit **1000** can determine the phase mismatch parameter $\Delta\theta_{BBk}$ for all adjacent channel elements, then determine the characteristic value $(\beta \mathbf{1}_2)$ for the transmission line L_{TL} based on all phase mismatch parameters $\Delta\theta_{BBk}$, as expressed by Eq. (6) and Eq. (7):

$$\sum_{k=1}^{n-1}\Delta\theta_{BBk}=-(n-1)\beta l_2+\theta_1-\theta_n \quad \text{Eq. (6)}$$

where n is a number of the channel elements **106** separated by length $\mathbf{1}_2$.

$$\beta l_2=\frac{\theta_1-\theta_n-\sum_{k=1}^{n-1}\Delta\theta_{BBk}}{n-1} \quad \text{Eq. (7)}$$

Eq. (7) shows that the characteristic value $(\beta \mathbf{1}_2)$ for the transmission line L_{TL} only depends on the phase mismatch parameter $\Delta\theta_{BBk}$ and $(\theta_1-\theta_n)$. Further, Eq. (7) also indicates that the characteristic value $(\beta \mathbf{1}_2)$ may be determined based on a sum of the phase mismatch parameter $\Delta\theta_{BBk}$ (characteristic differences). The phase mismatch parameter $\Delta\theta_{BBk}$ is known by the phases θ_k and θ_{k+1}. The term $(\theta_1-\theta_n)$ can be kept within 10 degree error by circuit design or circuit configuration, therefore the error of the estimated phase mismatch $(\theta_k-\theta_{k+1})$ can be kept within 10/(n−1) degree. It can be seen in Eq. (7) that the error of the determined characteristic value $(\beta \mathbf{1}_2)$ decreases with an increase in the number n of the channel elements **106** separated by length $\mathbf{1}_2$. It follows that the accuracy of the estimated phase mismatch $(\theta_k-\theta_{k+1})$ increases with the number n of the channel elements **106**. In some embodiments, all channel elements **106** are placed in a loop, each spaced by the transmission line length $\mathbf{1}_2$ to the adjacent channel element **106**, the phase θ_n for the last channel element **106** can be considered as the phase θ_1 for the first channel element **106**, and the term $(\theta_1-\theta_n)$ can be reduced to 0, consequently the estimated phase mismatch $(\theta_k-\theta_{k+1})$ can also be kept at 0 degree.

The phase calibration method **4** can determine the phase mismatch $(\theta_k-\theta_{k+1})$ according to Eq. (8).

$$\theta_k-\theta_{k+1}=\Delta\theta_{BBk}+\beta l_2=\Delta\theta_{BBk}+\frac{\theta_1-\theta_n-\sum_{k=1}^{n-1}\Delta\theta_{BBk}}{n-1} \quad \text{Eq. (8)}$$

The calibration circuit **1000** can adjust the receiver phase of the second channel element **106***b* with reference to the receiver phase of the first channel element **106***a* (S**418**), then run Steps S**408**-S**412** again for determining an updated channel response R**1'** of the second channel element **106***b*. Accordingly, the receiver phases of the receiver front ends can be adjusted by the digital phase control signals. Based on the updated channel response R**1'**, the calibration circuit **1000** can determine whether $(\theta_{BB0}-\theta_{BB1}')$ approaches to the characteristic value $(\beta \mathbf{1}_2)$ within a predetermined range set during the circuit design. The calibration circuit **1000** can adjust the receiver phase until $(\theta_{BB0}-\theta_{BB1}')$ is substantially the same as the characteristic value $(\beta \mathbf{1}_2)$.

Following by the phase adjustment for the second channel element, the calibration circuit **1000** next can adjust the receiver phase for the next channel element **106***c* with reference to the receiver phase of the previous channel element **106***b* and determine the new channel response R**2'** after the phase calibration. Based on the newly determined channel response R**2'**, the calibration circuit **1000** can further determine whether the phase mismatch parameter $(\theta_{BB1}-\theta_{BB2}')$ is substantially the same as the characteristic value $(\beta \mathbf{1}_2)$. If so, the phase calibration for the third receiver front end is then completed, and if not, the calibration circuit **1000** can continue adjusting the receiver phase of the third channel element **106***c* until the $(\theta_{BB1}-\theta_{BB2}')$ approaches the characteristic value $(\beta \mathbf{1}_2)$ to the predetermined range.

The calibration circuit **1000** can perform the phase adjustment procedure for the remaining channel element **106***d*. The phase calibration method **4** is completed and exited after all receiver front ends of the channel elements **106** have been calibrated for the channel-to-channel phase mismatch.

Taking the phased-array device **2** as an example, to determine the phase mismatches for the receiver front ends RX**0**-RX**7**, the phase calibration method **4** is implemented to turn on the loopback PA **108** and turn off the loopback LNA **110** (S**400**), turn the first receiver front end RX**0** on and the remaining receiver front ends RX**1**-RX**7** off (S**402**), initiate the test signal St' on the transmission line LTL by loopback PA **108** (S**404**), obtain the first channel response R**0** by the first receiver front end RX**0** (S**406**), hence complete the round for determining the channel response R**0** for the first receiver front end RX**0**. The phase calibration method **4** then carries on to obtain the other 7 channel responses R**1**-R**7** for the remaining receiver front ends RX**1**-RX**7** based on the loop outlined

in Step S408-S414 until the channel responses for all receiver front ends RX0-RX7 are collected. The phase calibration method **4** next is implemented to calculate the characteristic value ($\beta \mathbf{1}_2$) by applying the channel responses R0-R7 into Eq. (5), (6), and (7) (S416), and adjust phase settings for the receiver front ends RX1-RX7 by the digital phase control signals until all phase mismatch parameters (θ_{BB0}-θ_{BB1}), (θ_{BB1}-θ_{BB2}), . . . , (θ_{BB7}-θ_{BB6}) equal to the characteristic value exp($\beta \mathbf{1}_2$) (S418).

The phase calibration method **4** employs a plurality of channel responses Rk for computing the characteristic value ($\beta \mathbf{1}_2$) of the transmission line segment $\mathbf{1}_2$, thereby reducing the error in the estimated characteristic value ($\beta \mathbf{1}_2$) and increasing the accuracy for determining the channel-to-channel phase mismatch (θ_k-θ_{k+1}). Further, when all channel elements **106** are placed in a loop with an equal distance $\mathbf{1}_2$ to the adjacent channel elements **106**, the error for phase mismatch determination can be reduced to 0.

FIG. **5** is a flowchart of a channel-to-channel gain calibration method **5** for the transmission paths according to an embodiment of the invention, incorporating the phased array devices **1** or **2** in the invention.

Upon startup of the gain calibration method **5**, the phased-array device **1** is configured to activate the loopback LNA **110**, deactivate the loopback PA **108**, and prepare the loopback LNA **110** for initiating the test signal St on the transmission line L_{TL} (S500). Further, the phased-array device **1** is configured to turn only on the first transmitter front end of the channel element, such as the channel element **106***a*, while keeping the transmitter front ends the rest of the channel elements (channel **106***b-d*) off (S502), so that the channel **106***a* is the only one channel that can transmit the signals onto the transmission line L_{TL}. The transmitter front end in the channel **106***a* is set to a default digital gain setting D_{G0} and a default digital phase setting $D_{\Phi 0}$. The first channel element **106***a* can send the test signal St' onto the transmission line L_{TL} for the loopback LNA **110** to pick up (S504). In response, the loopback LNA **110** can acquire the test signal St', down-convert and digitize the test signal St' to derive a first transmitter channel response R0 for the calibration circuit **1000** to determine the channel-to-channel mismatch (S506). The first transmitter channel response R0 can be expressed as $S_{BB0}\exp(j\theta_{BB0})$, with SBB0 being the amplitude and θ_{BB0} being the phase shift of the channel response signal R0 with reference to the test signal St.

The phased-array device **1** can then turn on only the second transmitter front end of the channel element **106***b* and turn off the transmitter front ends of the remaining channel elements **106***a, c*-d (S508), send the test signal St' again onto the transmission line L_{TL} through the second transmitter front end (S510), and obtain the test signal St' through the loopback LNA **110** (S512). While delivering the test signal St' onto the transmission line L_{TL}, the transmitter front end of the channel **106***b* is set to a default digital gain setting D_{G1} and a default digital phase setting $D_{\Phi 1}$. The test signal St' undergoes every circuit element and process on the transmission path via the second channel element **106***b* and loops back to the baseband circuit **100** via the loopback LNA **110** to be the second channel response R2 for determining the channel-to-channel transmitter gain mismatch. The second transmitter channel response R1 can be expressed as $S_{BB1}\exp(j\theta_{BB1})$, with SBB1 being the amplitude and θ_{BB1} being the phase shift of the channel response signal R1 with reference to the test signal St. The channel-to-channel gain calibration method **5** only turn on one channel element **106** at a time, to measure the corresponding channel response specifically for the turned-on channel.

Next, the gain calibration method **5** continues to switch the active channel for taking the next channel response Rk, with k being the channel count **0-3** in the case of phased-array device **1**. The calibration circuit **1000** or a channel count circuit (not shown) can determine whether all channels in the phased-array device **1** have the channel response measurements S_{BBK} taken (S514). When all channel responses RK are collected, the calibration circuit **1000** can calculate characteristic value exp($-\alpha \mathbf{1}_2$) for the transmission line L_{TL} according to the amplitudes S_{BBk} of the channel responses RK (S516). The calibration circuit **1000** can compute a gain mismatch parameter ΔS_{BBk} between any two adjacent channel elements **106** according to Eq. (1). After the gain mismatch parameters ΔS_{BBk} for all adjacent channel elements are computed, the calibration circuit **1000** can determine the characteristic value exp($-\alpha \mathbf{1}_2$) for the transmission line L_{TL} based on all gain mismatch parameters ΔS_{BBk} according to Eq. (2) and Eq. (3), and determine the gain mismatch (G_k/G_{k+1}) according to Eq. (4), and adjust the gain settings for the transmitter front ends of the channel elements **106** *b-d* according to the estimated gain mismatch (G_k/G_{k+1}) by the gain adjustment procedure outlined in the gain calibration method **3**. Steps S516 to S518 in FIG. **5** are identical to Step S316-S318 in FIG. **3**, relevant explanation for the gain adjustment can be found in the preceding paragraphs. The gain calibration method **5** is completed and exited after the transmitter front ends of the channel elements **106***b-d* have been calibrated for the channel-to-channel gain mismatch.

Taking the phased-array device **2** as an example, to determine the gain mismatches for the transmitter front ends TX0-TX7, the gain calibration method **5** is implemented to turn on the loopback LNA **110** and turn off the loopback PA **108** (S500), turn the first transmitter front end TX0 on and the remaining transmitter front ends TX1-TX7 off (S502), place the test signal St' on the transmission line L_{TL} by the first transmitter front end TX0 (S504), obtain the first channel response R0 by the loopback LNA **110** (S506), hence complete the round for determining the channel response R0 for the first transmitter front end TX0. The gain calibration method **5** then carries on to obtain the other 7 channel responses R1-R7 for the remaining transmitter front ends TX1-TX7 based on the loop outlined in Step S508-S514 until the channel responses for all transmitter front ends TX0-TX7 are collected. The gain calibration method **5** next is implemented to calculate the characteristic value exp($-\alpha \mathbf{1}_2$) by applying the channel responses R0-R7 into Eq. (1), (2), and (3) (S516), and adjust gain settings for the transmitter front ends TX1-TX7 by the digital gain control signals until all gain mismatch parameters

$$\frac{S_{BB0}}{S_{BB1}}, \frac{S_{BB1}}{S_{BB2}}, \ldots, \frac{S_{BB6}}{S_{BB7}}$$

equal to the characteristic value exp($-\alpha \mathbf{1}_2$) (S518).

The gain calibration method **5** employs a plurality of channel responses Rk for computing the characteristic value exp ($-\alpha \mathbf{1}_2$) of the transmission line segment $\mathbf{1}_2$, thereby reducing the error in estimated characteristic value exp($-\alpha \mathbf{1}_2$) and increasing the accuracy for determining the channel-to-channel gain mismatch. Further, when all channel elements **106** are placed in a loop with an equal distance $\mathbf{1}_2$ to the adjacent channel elements **106**, the error for gain mismatch determination can be reduced to 0.

FIG. **6** is a flowchart of a channel-to-channel phase calibration method **6** for the transmission paths according to an

embodiment of the invention, incorporating the phased array devices **1** or **2** in the invention.

Steps S**600** through S**614** are identical to Steps S**500** through S**514** in FIG. **5**, Steps S**616** through S**618** are identical to Steps S**416** through S**418** in FIG. **4**, reference therefor can be found in the preceding paragraph and will not be repeated here for brevity. Accordingly, the channel response R**1** for the first channel element **106***a* can be expressed by $S_{BB1}\exp(j\theta_{BB1})$, the channel response R**2** for the second channel element **106***b* can be expressed by $S_{BB2}\exp(j\theta_{BB2})$. For the channel-to-channel phase calibration, the calibration circuit **1000** serves to reduce or remove the phase difference between the transmitter front ends of the channel elements **106**, i.e., $\theta_{BBk}-\theta_{BB(k+1)}\approx 0$.

Taking the phased-array device **2** as an example, to determine the phase mismatches for the transmitter front ends TX**0**-TX**7**, the phase calibration method **6** is implemented to turn on the loopback LNA **110** and turn off the loopback PA **108** (S**600**), turn the first transmitter front end TX**0** on and the remaining transmitter front ends TX**1**-TX**7** off (S**602**), place the test signal St' on the transmission line L_{TL} by the first transmitter front end TX**0** (S**604**), obtain the first channel response R**0** by the loopback LNA **110** (S**606**), hence complete the round for determining the channel response R**0** for the first transmitter front end TX**0**. The phase calibration method **6** then carries on to obtain the other 7 channel responses R**1**-R**7** for the remaining transmitter front ends TX**1**-TX**7** based on the loop outlined in Step S**608**-S**614** until the channel responses for all transmitter front ends TX**0**-TX**7** are collected. The phase calibration method **6** next is implemented to calculate the characteristic value ($\beta\mathbf{1}_2$) by applying the channel responses R**0**-R**7** into Eq. (5), (6), and (7) (S**616**), and adjust phase settings for the transmitter front ends TX**1**-TX**7** by the digital phase control signals until all phase mismatch parameters ($\theta_{BB0}-\theta_{BB1}$), ($\theta_{BB1}-\theta_{BB2}$), . . . , ($\theta_{BB7}-\theta_{BB6}$) equal to the characteristic value $\exp(\beta\mathbf{1}_2)$ (S**618**).

The phase calibration method **6** employs a plurality of channel responses Rk for computing the characteristic value ($\beta\mathbf{1}_2$) of the transmission line segment $\mathbf{1}_2$, thereby reducing the error in the estimated characteristic value ($\beta\mathbf{1}_2$) and increasing the accuracy for determining the channel-to-channel phase mismatch ($\theta_k-\theta_{k+1}$) for the transmitter front ends. Further, when all channel elements **106** are placed in a loop with an equal distance $\mathbf{1}_2$ to the adjacent channel elements **106**, the error for phase mismatch determination can be reduced to 0.

As used herein, the term "determining" encompasses calculating, computing, processing, deriving, investigating, looking up (e.g., looking up in a table, a database or another data structure), ascertaining and the like. Also, "determining" may include resolving, selecting, choosing, establishing and the like.

The various illustrative logical blocks, modules and circuits described in connection with the present disclosure may be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array signal (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, but in the alternative, the processor may be any commercially available processor, controller, microcontroller or state machine.

The operations and functions of the various logical blocks, modules, and circuits described herein may be implemented in circuit hardware or embedded software codes that can be accessed and executed by a processor.

While the invention has been described by way of example and in terms of the preferred embodiments, it is to be understood that the invention is not limited to the disclosed embodiments. To the contrary, it is intended to cover various modifications and similar arrangements (as would be apparent to those skilled in the art). Therefore, the scope of the appended claims should be accorded the broadest interpretation so as to encompass all such modifications and similar arrangements.

What is claimed is:

1. A calibration method, performed on a phased array device comprising a plurality of channel elements coupled in parallel by a transmission line, the method comprising:

obtaining a plurality of channel responses corresponding to the channel elements through the transmission line, wherein each of the channel responses is obtained when one of the channel elements is turned on, and the rest of the channel elements are turned off;

calculating a characteristic value corresponding to the transmission line based on the obtained channel responses of the channel elements, wherein calculating the characteristic value comprises:

obtaining a plurality of characteristic differences between the channel responses; and

determining the characteristic value corresponding to the transmission line by the characteristic differences; and

adjusting a channel parameter of one of the channel elements based on the characteristic value of the transmission line.

2. The calibration method of claim **1**, wherein the channel elements are RF transmitter front-ends or RF receiver front-ends.

3. The calibration method of claim **1**, wherein when the channel elements are RF transmitter front-ends, the transmission line is coupled to output ports of the RF transmitter front-ends; when the channel elements are RF receiver front-ends, the transmission line is coupled to input ports of the RF receiver front-ends.

4. The calibration method of claim **1**, wherein each two adjacent channel elements of the channel elements are spaced by substantially a same length.

5. The calibration method of claim **1**, wherein when the channel elements are RF transmitter front-ends, the step of obtaining the plurality of channel responses corresponding to the channel elements through the transmission line comprises:

sending a test signal to the turned-on RF transmitter frond-end when the rest of the RF transmitter front-ends are turned off;

receiving a signal outputted by the turned-on RF transmitter frond-end through the transmission line; and

determining the channel response corresponding to the turned-on RF transmitter frond-end based on the received signal.

6. The calibration method of claim **1**, wherein when the channel elements are RF receiver front-ends, the step of obtaining the plurality of channel responses corresponding to the channel elements through the transmission line comprises:

sending a test signal to the turned-on RF receiver frond-end through the transmission line when the rest of the RF receiver front-ends are turned off;

receiving a signal outputted by the turned-on RF receiver frond-end; and

determining the channel response corresponding to the turned-on RF receiver frond-end based on the received signal.

7. The calibration method of claim **1**, wherein the channel responses corresponding to the channel elements are amplitude values or phase values of signals outputted by the channel elements.

8. The calibration method of claim **1**, wherein the channel responses comprises amplitude values outputted by the channel elements, and the step of calculating the characteristic value corresponding to the transmission line based on the obtained channel responses of the channel elements comprises:

determining the characteristic value based on a product of the characteristic differences.

9. The calibration method of claim **1**, wherein the channel responses comprises phase values outputted by the channel elements, and the step of calculating the characteristic value corresponding to the transmission line based on the obtained channel responses of the channel elements comprises:

determining the characteristic value based on a sum of the characteristic differences.

10. The calibration method of claim **1**, wherein when the channel responses corresponding to the channel elements are amplitude values of signals outputted by the channel elements, the adjusted channel parameter is a gain setting of the corresponding channel element; when the channel responses corresponding to the channel elements are phase values of signals outputted by the channel elements, the adjusted channel parameter is a phase setting of the corresponding channel element.

11. The calibration method of claim **1**, wherein the steps of calculating the characteristic value corresponding to the transmission line based on the obtained channel responses of the channel elements comprises:

obtaining a plurality of characteristic differences between each two of the channel responses;

determining the characteristic value corresponding to the transmission line by the characteristic differences.

12. A phased array device, comprising:

a transmission line;

a plurality of channel elements coupled in parallel by the transmission line; and

a calibration circuit, configured to obtain a plurality of channel responses corresponding to the channel elements through the transmission line, calculate a characteristic value corresponding to the transmission line based on the obtained channel responses of the channel elements, and adjust a channel parameter of one of the channel elements based on the characteristic value of the transmission line, wherein the calibration circuit is configured to: obtain a plurality of characteristic differences between the channel responses; and determine the characteristic value corresponding to the transmission line by the characteristic differences, and

wherein each of the channel responses is obtained when one of the channel elements is turned on, and the rest of the channel elements are turned off.

13. The phased array device of claim **12**, wherein when the channel elements are RF transmitter front-ends, the transmission line is coupled to output ports of the RF transmitter front-ends; when the channel elements are RF receiver front-ends, the transmission line is coupled to input ports of the RF receiver front-ends.

14. The phased array device of claim **12**, wherein when the channel elements are RF transmitter front-ends, the calibration circuit is configured to send a test signal to the turned-on RF transmitter frond-end when the rest of the RF transmitter front-ends are turned off, receive a signal outputted by the turned-on RF transmitter frond-end through the transmission line, and determine the channel response corresponding to the turned-on RF transmitter frond-end based on the received signal.

15. The phased array device of claim **12**, wherein when the channel elements are RF receiver front-ends, the calibration circuit is configured to send a test signal to the turned-on RF receiver frond-end through the transmission line when the rest of the RF receiver front-ends are turned off, receive a signal outputted by the turned-on RF receiver frond-end; and determine the channel response corresponding to the turned-on RF receiver frond-end based on the received signal.

16. The phased array device of claim of claim **12**, wherein the channel responses comprises amplitude values outputted by the channel elements, and the calibration circuit is configured to determine the characteristic value based on a product of the characteristic differences.

17. The phased array device of claim of claim **12**, wherein the channel responses comprises phase values outputted by the channel elements, and the calibration circuit is configured to determine the characteristic value based on a sum of the characteristic differences.

18. The phased array device of claim **12**, wherein when the channel responses corresponding to the channel elements are amplitude values of signals outputted by the channel elements, the adjusted channel parameter is a gain setting of the corresponding channel element; when the channel responses corresponding to the channel elements are phase values of signals outputted by the channel elements, the adjusted channel parameter is a phase setting of the corresponding channel element.

19. The phased array device of claim **12**, wherein the calibration circuit is configured to:

obtain a plurality of characteristic differences between each two of the channel responses; and

determine the characteristic value corresponding to the transmission line by the characteristic differences.

* * * * *